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GEORGE R. BROWN CONVENTION CENTER

Pulsation Amplitude Effects of Altering Characteristics of Gas- Liquid Dampeners

Southwest Research Institute®:

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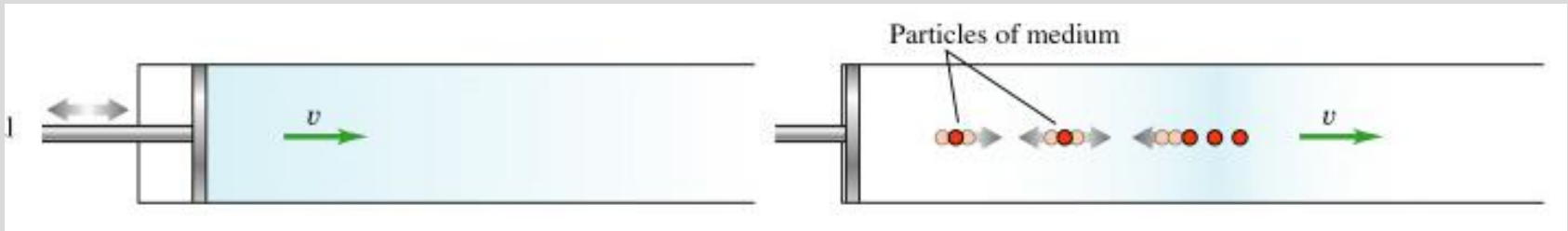
Speaker Biographies

- Sarah Simons is a Research Scientist in the Fluids Machinery Systems Section at Southwest Research Institute. In this position, she performs thermal and acoustic analyses of compressor and pump piping systems along with reciprocating compressor pulsation filter bottle design. She also leads projects in compressor and flow pulsation control research.
- Dr. Klaus Brun is the Program Director of the Machinery Program at Southwest Research Institute. His experience includes positions in engineering, project management, and management at Solar Turbines, General Electric, and Alstom. He holds six patents, authored over 150 papers, and published two textbooks on gas turbines.

PHYSICS OF PULSATIONS

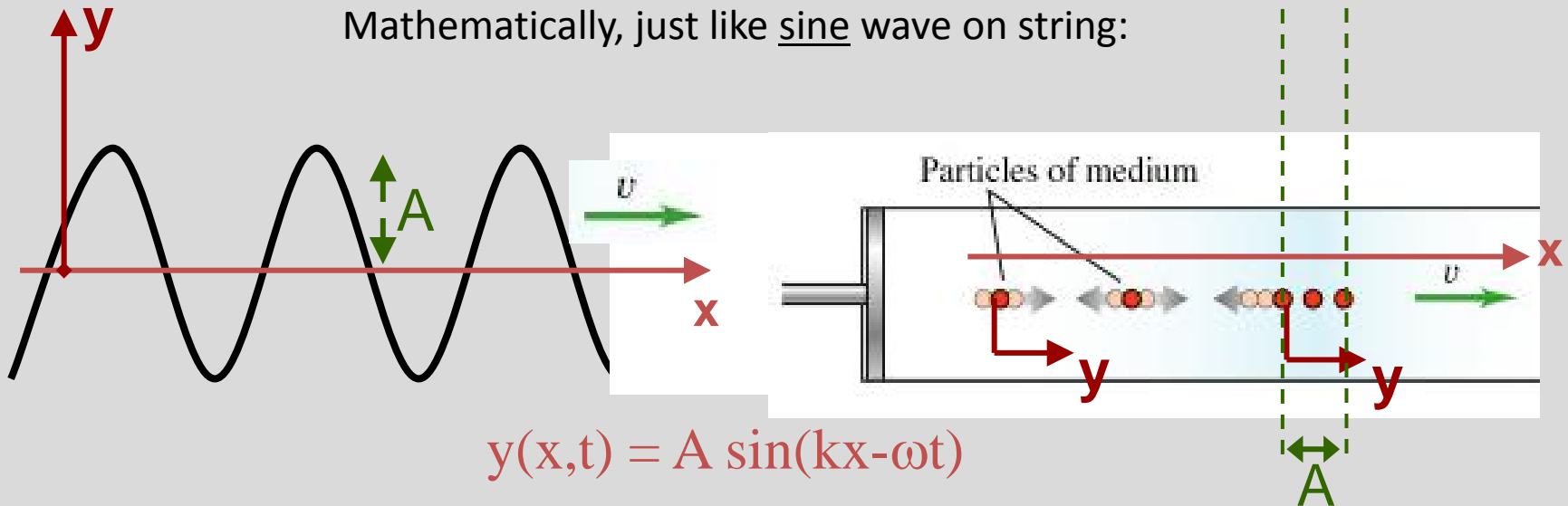
Pulsations: What are they?

- A traveling compression wave in a fluid.
- Waves are composed of two components: Pressure and Velocity
- Pressure waves move at the speed of sound. (Flow does not.)

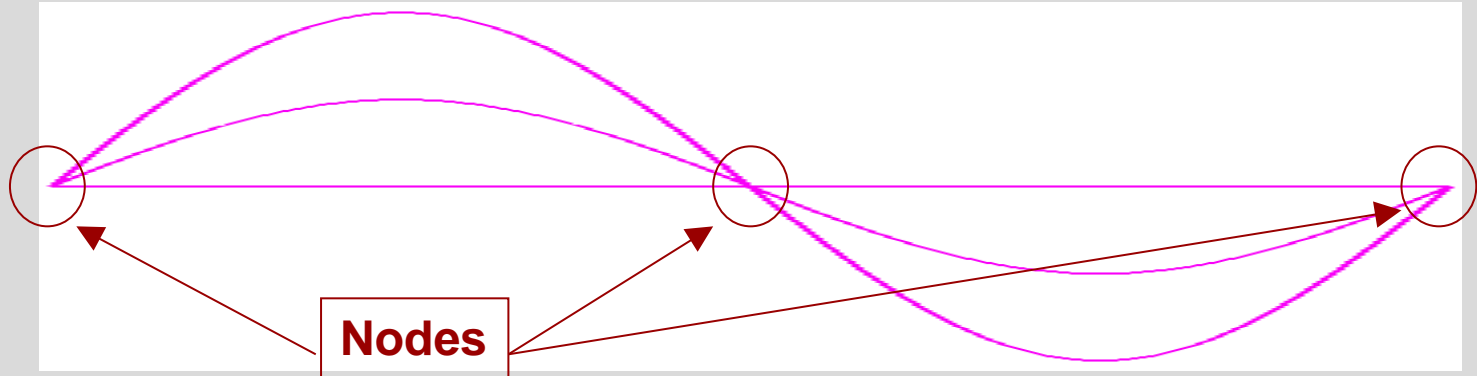


How do we acoustically model a pressure wave?

Mathematically, just like sine wave on string:



Standing Acoustic Waves



- Boundary conditions (open or closed) in finite length pipe support reflections
- A complex standing wave occurs when we have coherence between a **wave** and its **reflection**.
- Any complex wave can be described as superposition (combination) of sinusoids
 - Fourier analysis is decomposition of complex wave into its pure tone components--spectrum

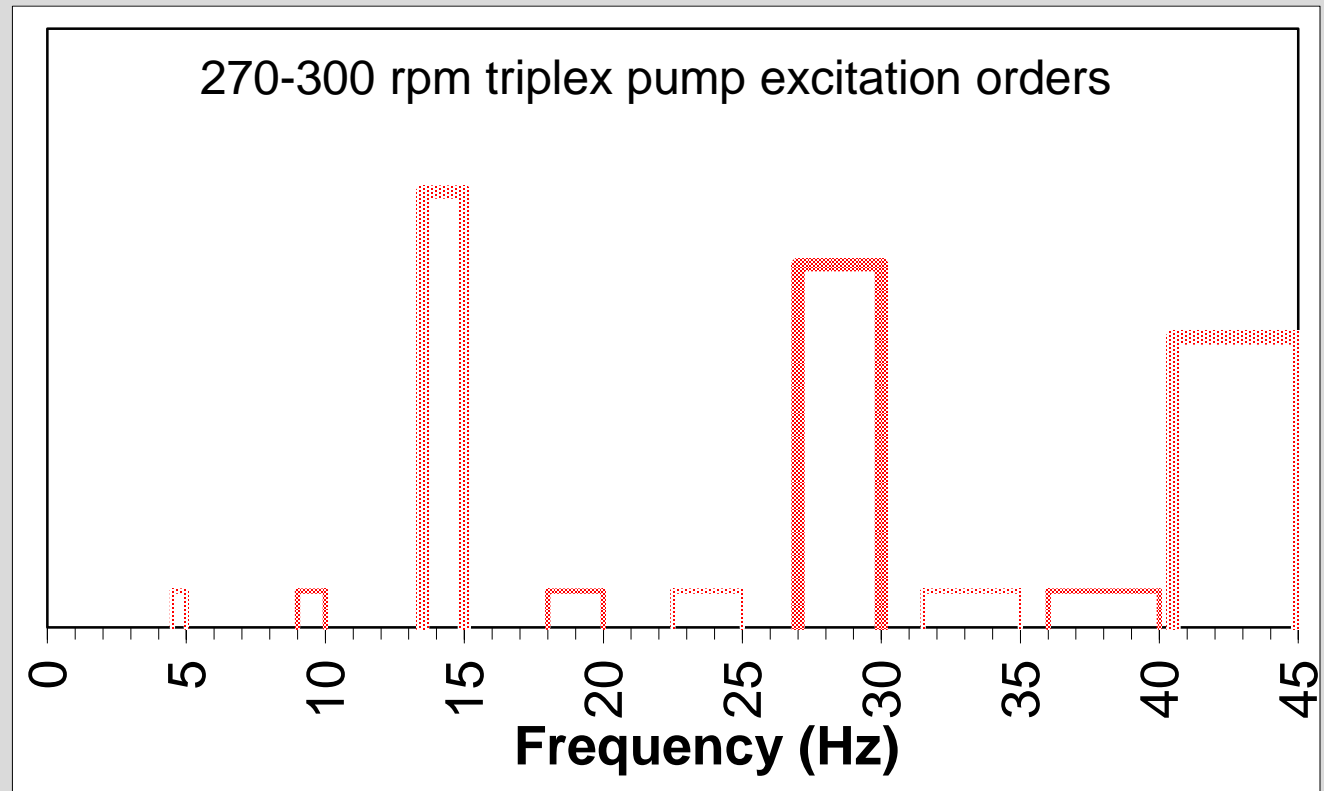
Pump Excitation Frequencies

$$f = n \frac{rpm}{60} \quad \text{where } n = 1, 2, 3, \dots$$

n = number of plungers

A 300 rpm triplex unit generates pulsation at 15, 30, 45,Hz

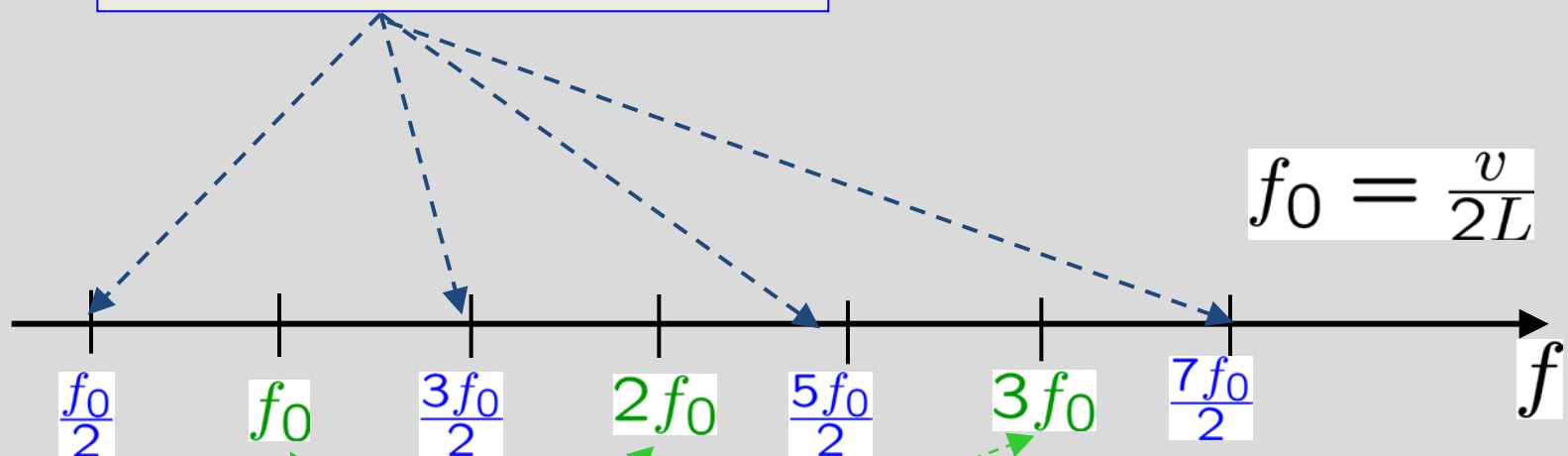
A 140 rpm duplex unit generates pulsation at 4.7, 9.3, 14.0,Hz



Typical Resonance Frequencies

$$f_n = n \frac{a}{4L} \quad n = 1, 3, 5 \dots$$

Different ends (open and closed on each end)

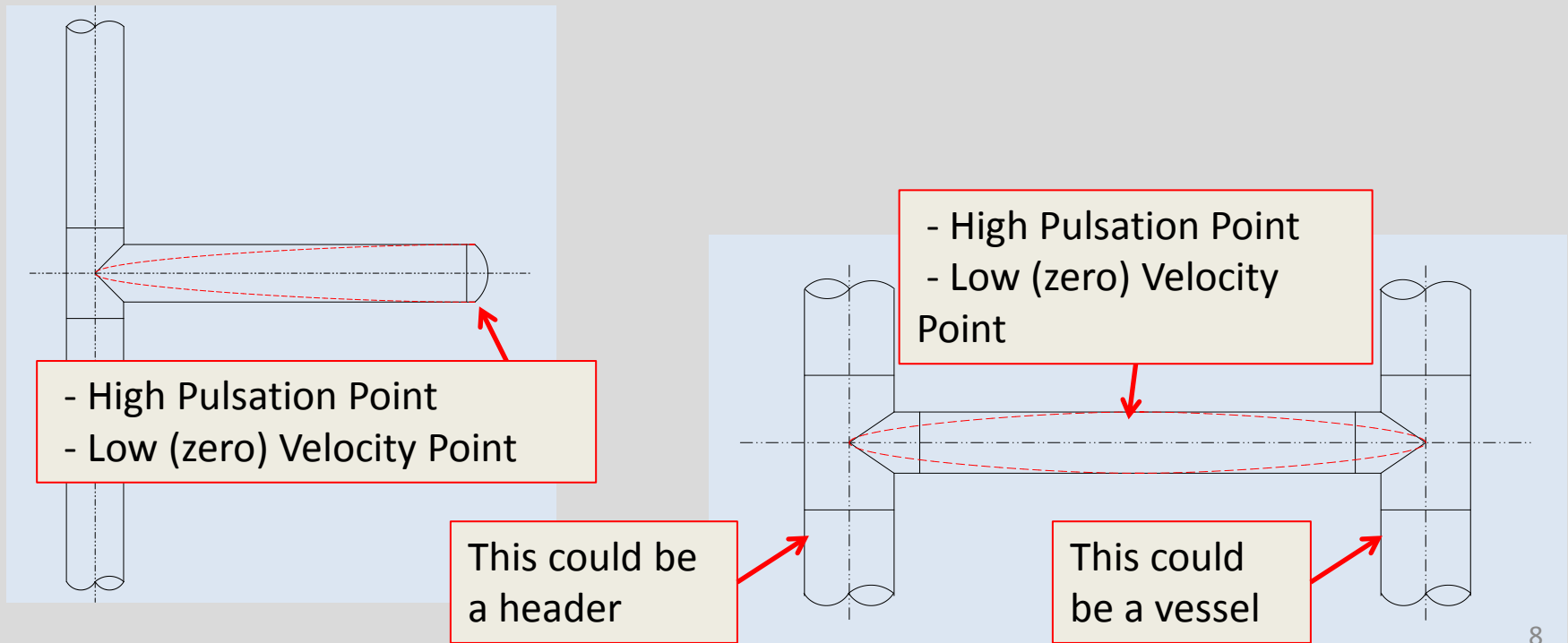


$$f_n = n \frac{a}{2L} \quad n = 1, 2, 3 \dots$$

Open or closed end (for both ends)

Pulsations to Resonance

- Positive displacement pumps generate pulsations at discrete frequencies
- Piping systems have acoustic reflection points creating standing waves
- High amplitude pulsations (RESONANCE) occur when driving frequency coincides with acoustic natural frequencies



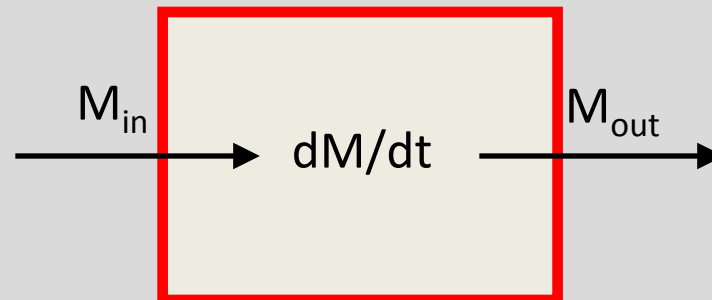
Transient versus Steady State Analysis

- Steady Analysis:

- Mass is Conserved: $M_1 + M_2 + M_3 \dots = 0$
- Force Balance: $F_1 + F_2 + F_3 \dots = 0$
- Energy is Conserved: $E_1 + E_2 + E_3 \dots = 0$

- Transient Analysis:

- Mass is Conserved: $M_1 + M_2 + M_3 \dots = dM/dt$
- Force Balance: $F_1 + F_2 + F_3 \dots = m \cdot a$
- Energy is Conserved: $E_1 + E_2 + E_3 \dots = dE/dt$



Governing Equations:

1-D Navier-Stokes Equations with Energy

Conservation of Mass:

$$\frac{\partial \rho}{\partial t} + \frac{\partial(\rho u)}{\partial x} = 0$$

Pressure
Forces

Conservation of Momentum:

Fluid
Inertia

$$\rho \frac{\partial u}{\partial t} + \rho u \frac{\partial u}{\partial x} + \frac{\partial p}{\partial x} = \mu \nabla^2 u$$

Viscous
Forces

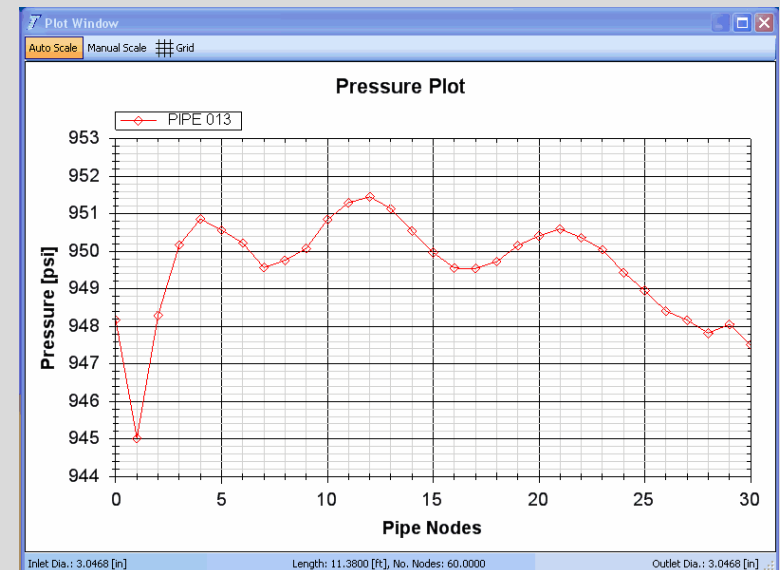
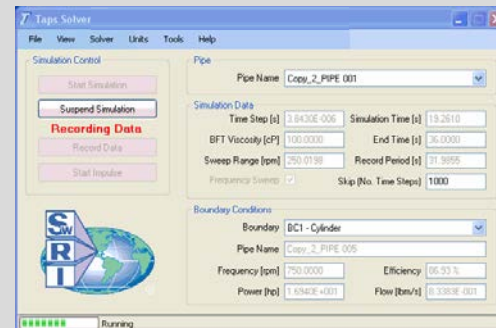
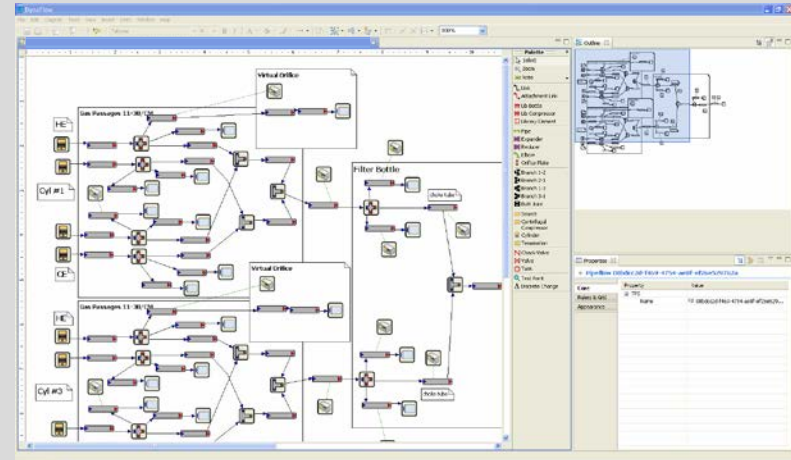
Conservation of Energy:

$$\rho c_v \frac{\partial T}{\partial t} + \rho c_v u \frac{\partial T}{\partial x} = k \nabla^2 T + \Phi$$

Viscous
Dissipation
Function

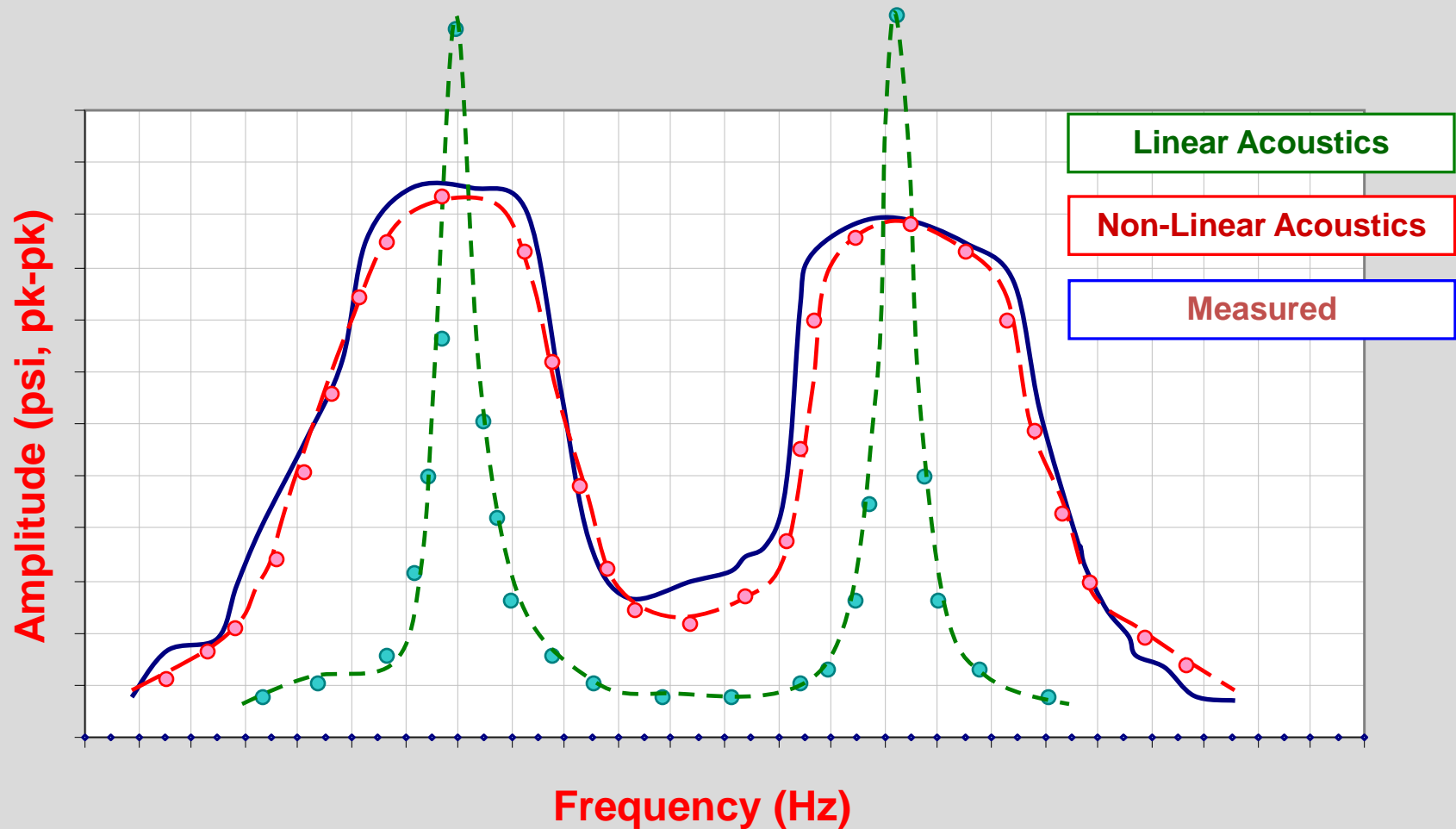
Transient Navier-Stokes Fluid Model SwRI

- TAPS
- One dimensional
- Time domain
- Navier-Stokes terms:
 - Inertia
 - Diffusion
 - Viscosity
 - Energy Dissipation

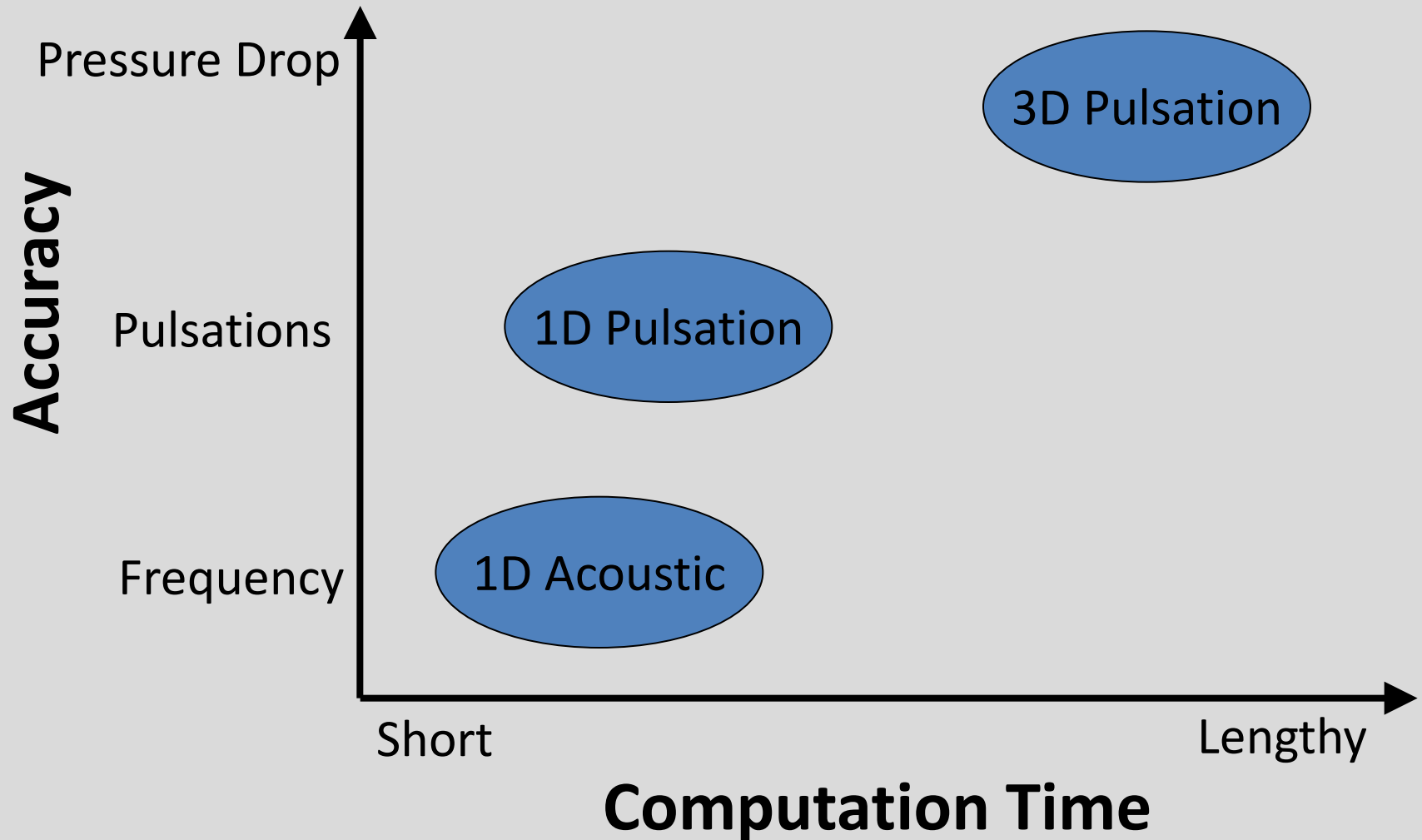


Flow Through a Pipe – Two Length Resonances

Piping Resonant Response: Linear vs. Non-Linear Acoustics



Modeling Techniques



Attenuation Methods - Gas

Orifice

Choking/Storing

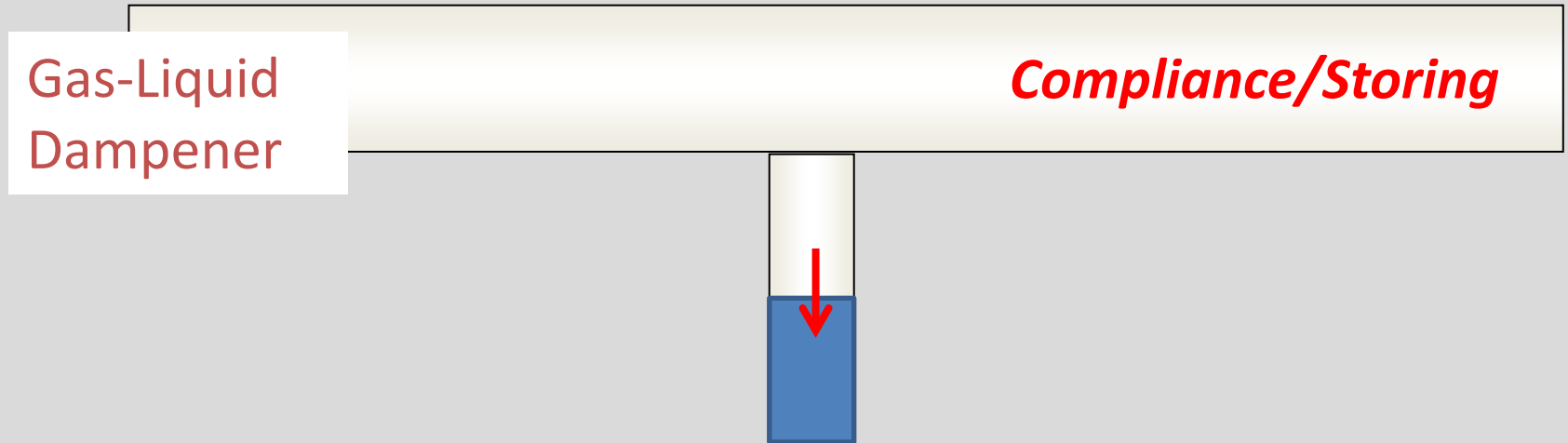
$\frac{1}{4}$ Wave Bottle/Filter

Shifting/Storing

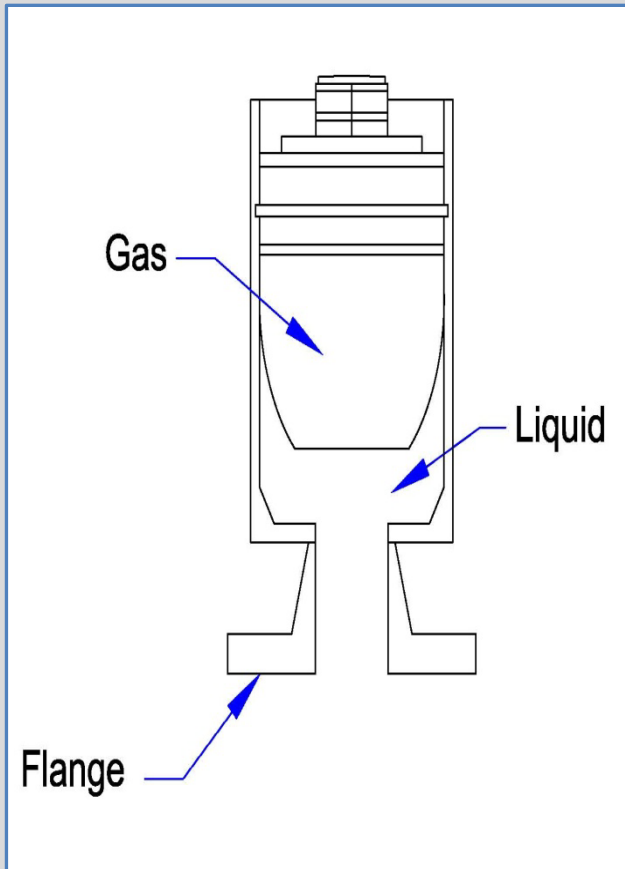
Side Branch

Shifting

Attenuation Methods - Liquid



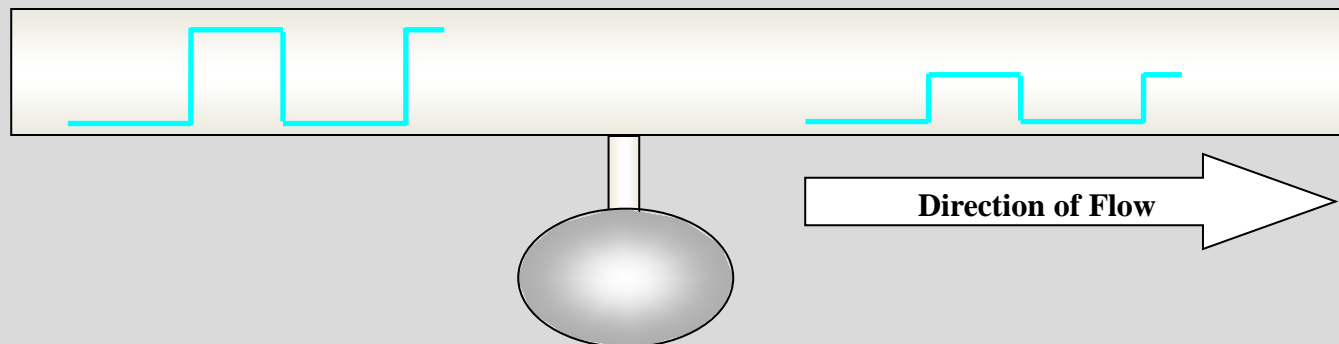
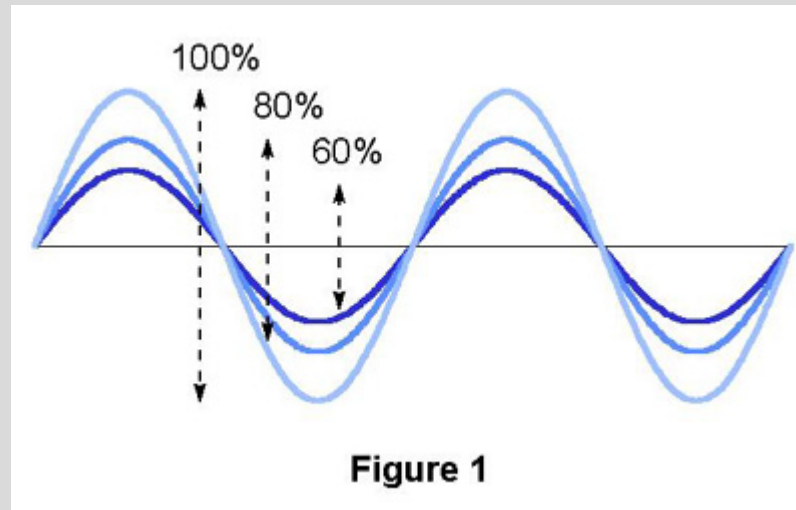
Gas-liquid Dampeners— Pulsation Attenuation



- Pre-charge gas-filled bladder to fixed percentage of line pressure
- Pre-charged gas creates relatively large effective liquid volume to absorb pulsations
- Gas volume acts as spring compressing and expanding with line pressure changes

Attenuation Through Surge Volume

- A large volume absorbs some of the peak of the dynamic pressure in the piping system and releases it when the pressure is low reducing the absolute amplitude of the pulsations.



EXPERIMENTAL WORK

Specific Problem

- What is the effect on pulsation amplitudes in positive displacement pump systems when altering various characteristics of gas-liquid dampeners?
 - Pre-charge pressure
 - Tee connection
 - Dampener connection
- Combination of laboratory testing and computer modeling performed to answer the question

Pump System Description

Triplex Water Pump

0.551" bore (1.40 cm)

0.945" stroke (2.40 cm)

1529 rpm

4.5 gpm (1.02 m³/hr)

Inlet Pressure: 45-50 psi

Outlet Pressure: 50-420

Used for injection into a flow loop

Gas-Liquid Dampener

15 cu. in. (0.25L)

Bladder type

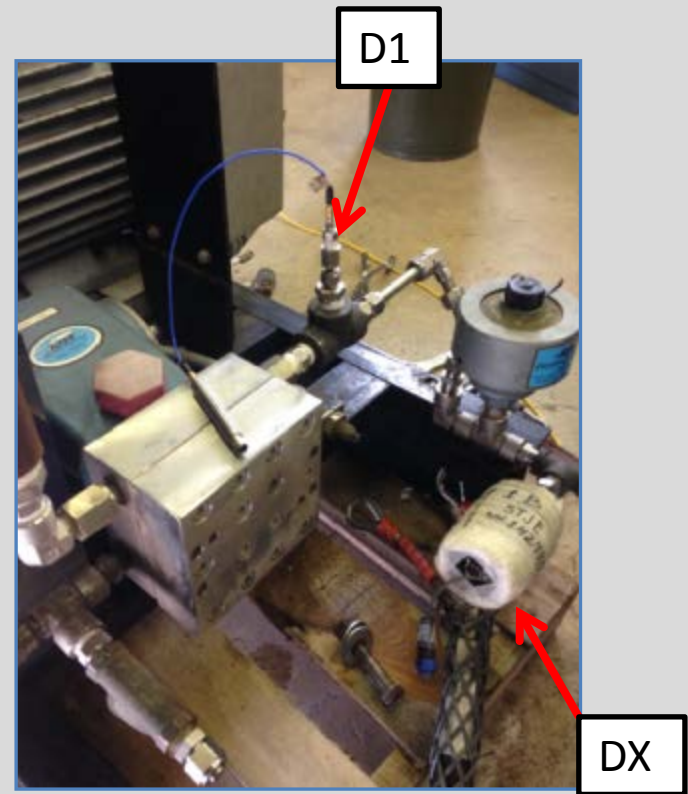
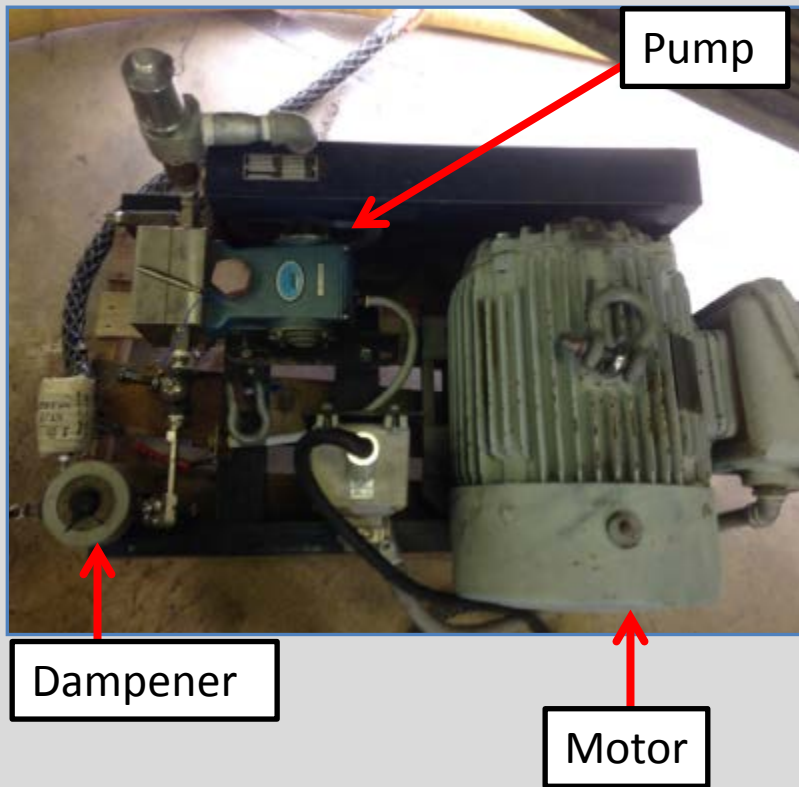
Manufacturer recommended
pre-charge: 80%
Pre-charged with Nitrogen

Discharge Piping System

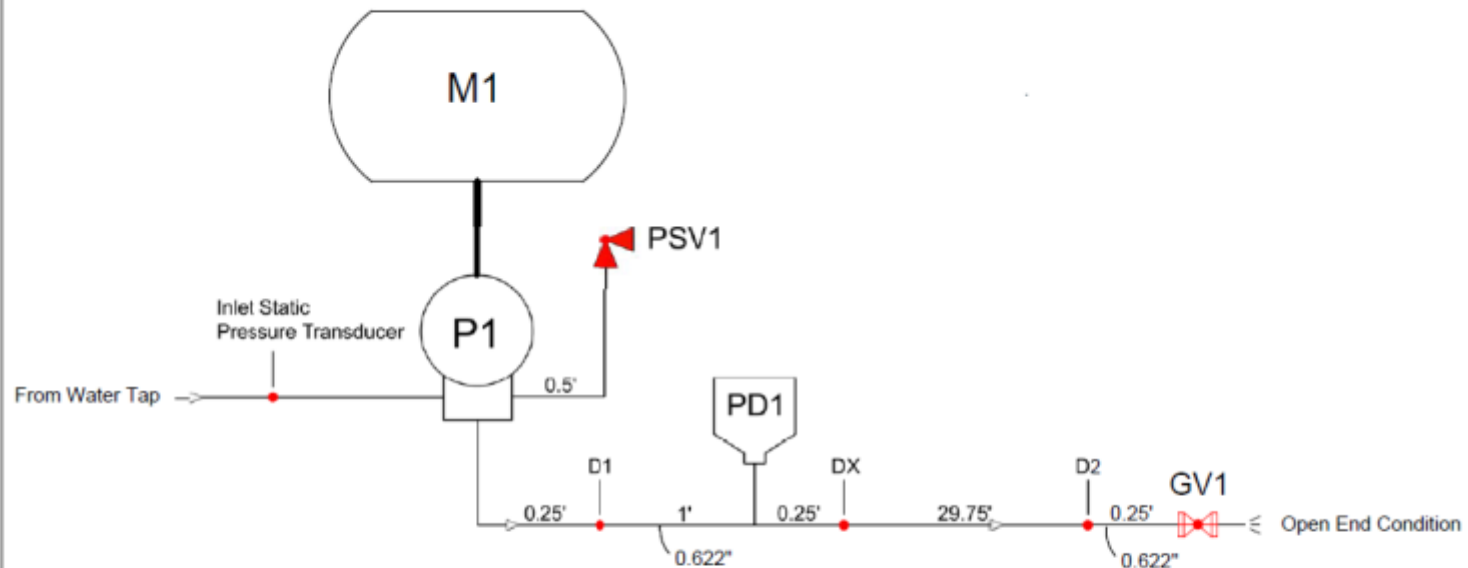
Operation of Pump

1. Tested only the discharge piping system. Discharge piping length varied by 3 feet to ensure running on resonance
2. Test was run over a range of suction to discharge pressure ratios and open/closed end conditions to achieve varying pulsation amplitudes at different frequencies
3. Dampener pre-charge varied to determine effect on pulsation amplitudes

Pump Used for Testing



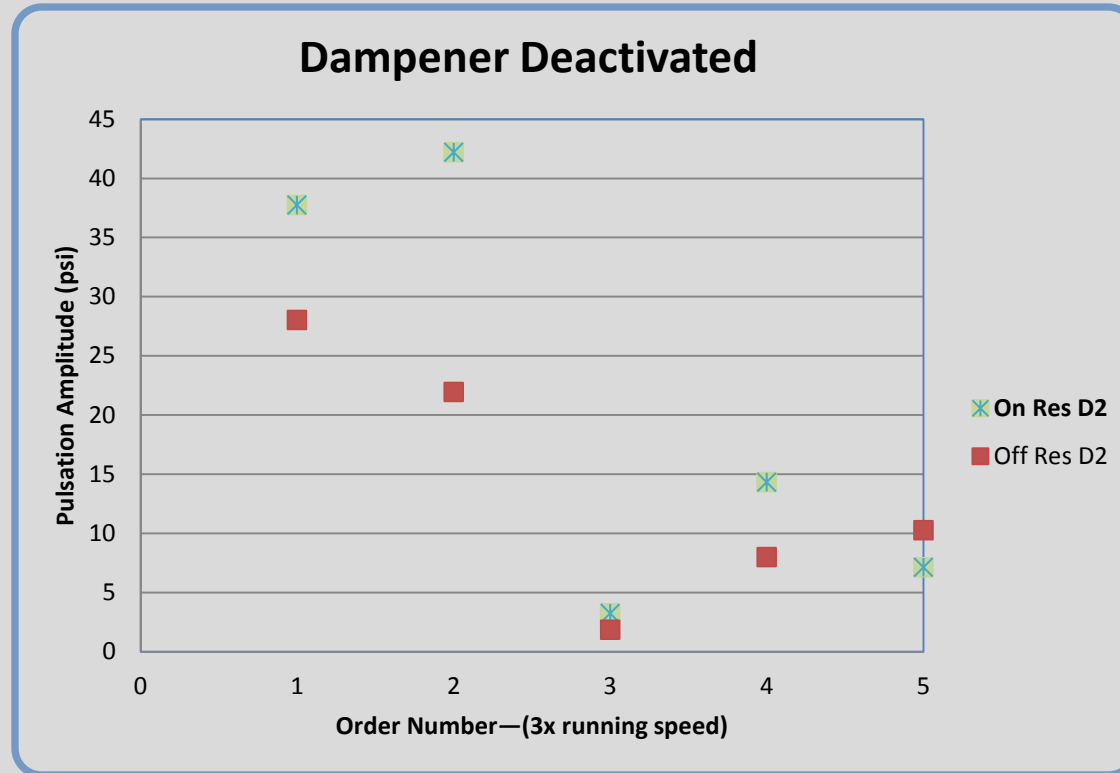
Schematic of Pump System



Equipment

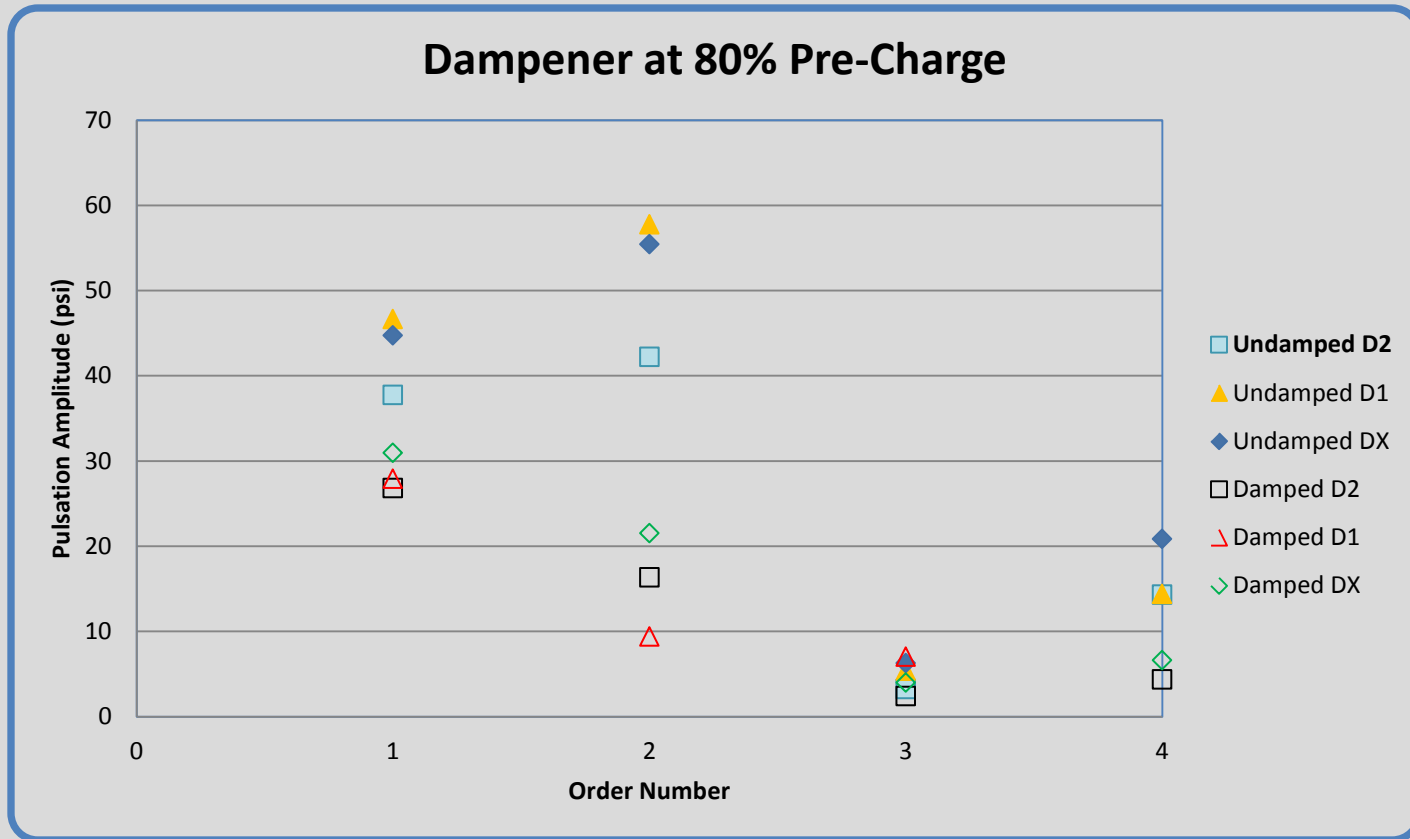
P1 - Triplex Pump (4.5 gpm)
M1 - Electric Motor (15 hp, 3530 rpm)
PD1 - Pulsation Dampener (15 cu. in.)
GV1 - Globe Valve (to adjust pressure ratio)
PSV1 - Pressure Safety Valve (1000 psi set point)
D1, DX, D2 - Dynamic Pressure Transducer

On Resonance vs. Off Resonance



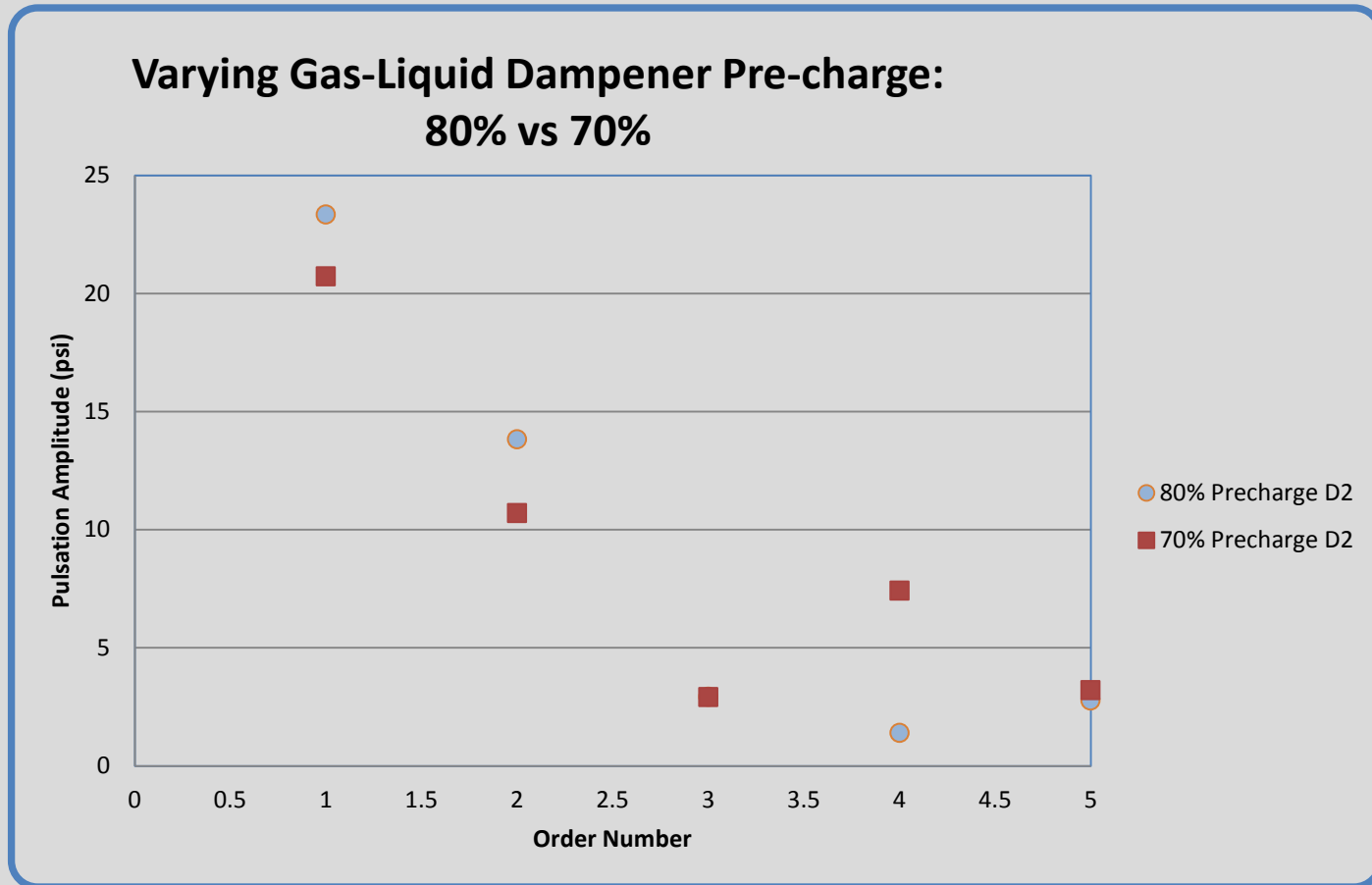
- Goal: To find a resonance in the system
- Varied piping by roughly 3 feet to verify hitting a resonant frequency
- Note: For clarity showing test point at pulsation maximum
- Pressure Ratio of 4

No Dampener vs. Dampener



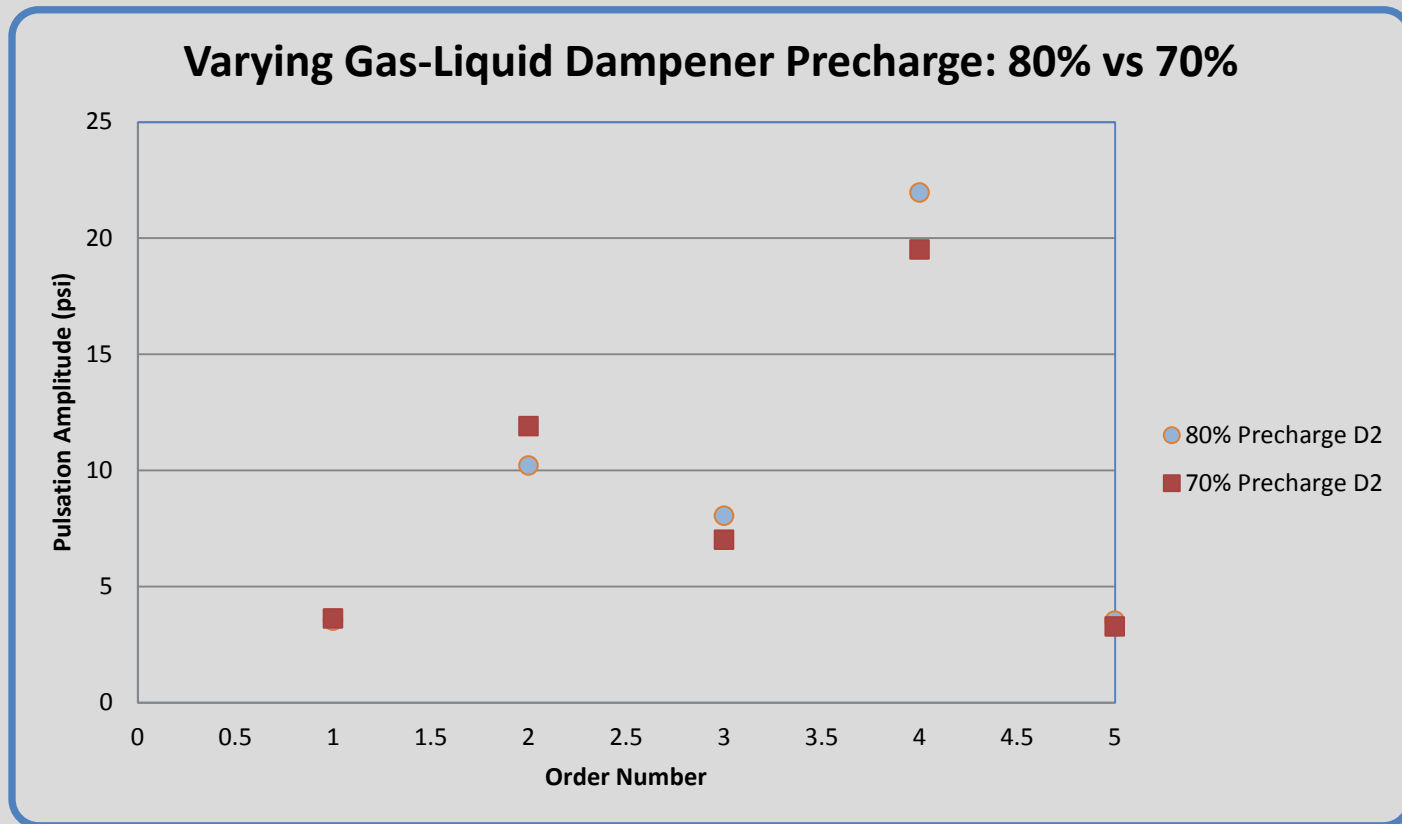
- Test points shown for resonant conditions
- Note: Dampener more effective at points downstream of connecting tee
- Pressure Ratio of 4

Varying Pre-charge, Pr=3.7, ~20% Open Valve



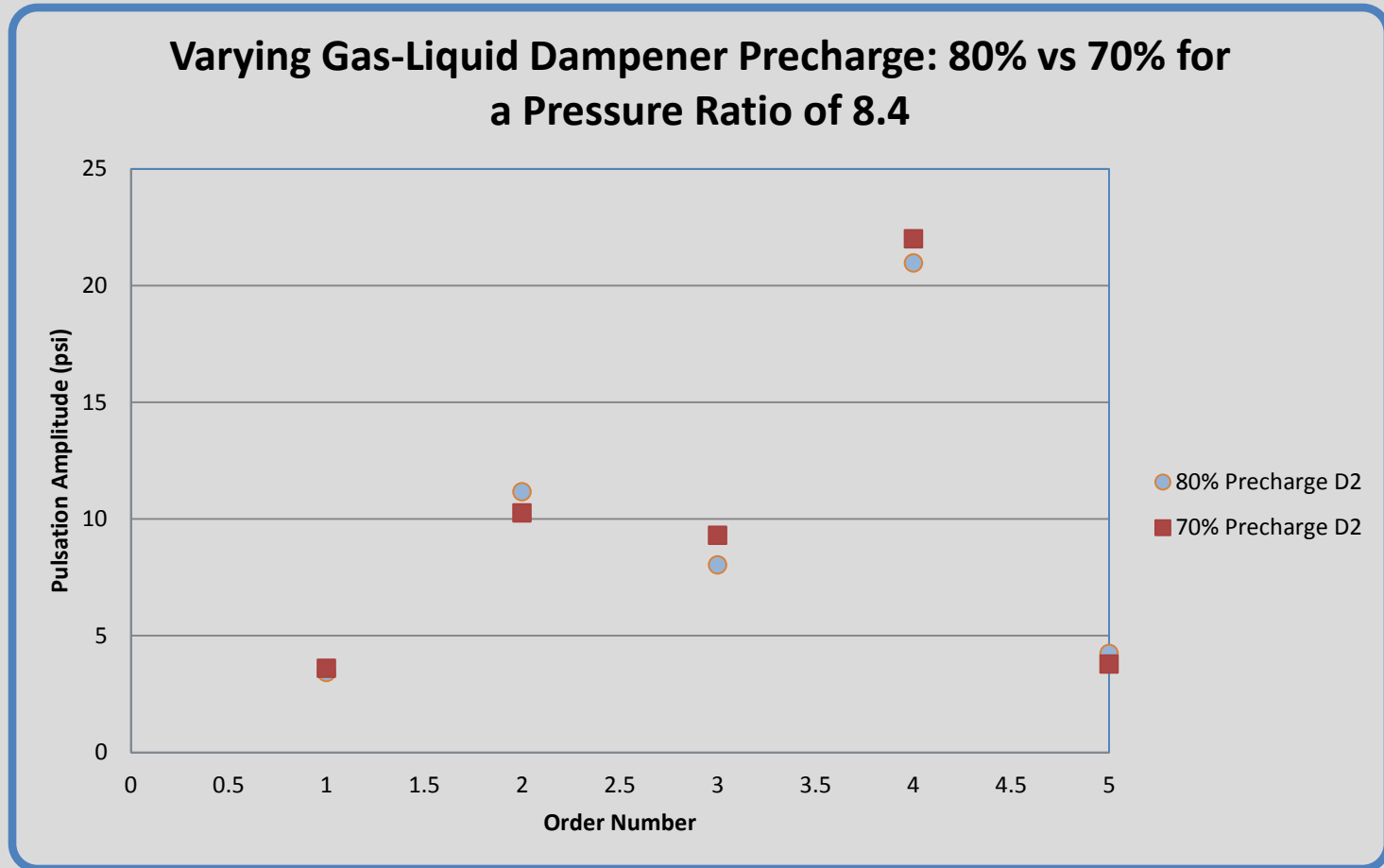
Note: Some orders better attenuated with 70% pre-charge.
Other orders better attenuated with 80% pre-charge.

Varying Pre-charge, $Pr=6.6$, ~70% Closed Valve



- Increased pressure ratio by closing discharge valve further
- Varying the end condition changed the frequencies in the piping system
- Same trend apparent: Some orders better attenuated with 70% pre-charge;
other orders better attenuated with 80% pre-charge

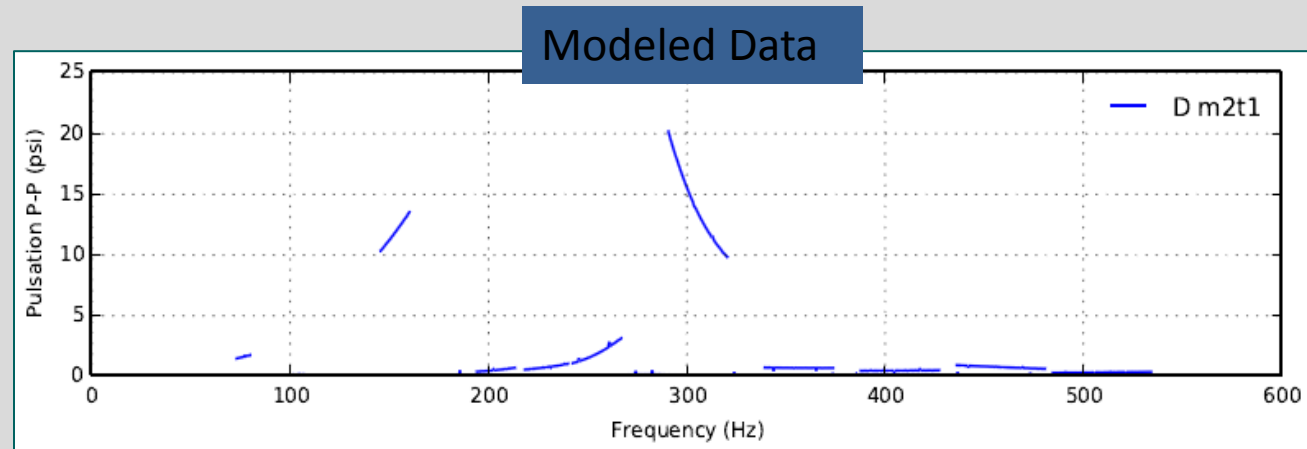
Varying Pre-charge, $Pr=8.4$, ~85% Closed Valve



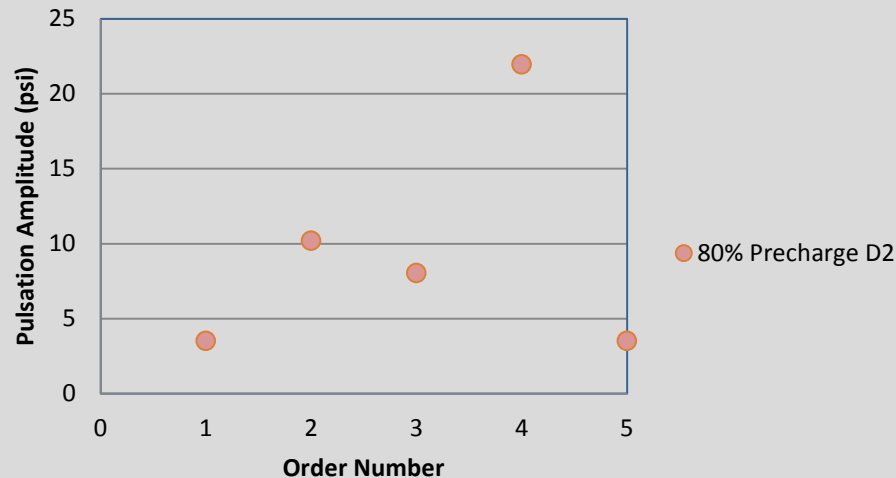
Dampener Pre-charge Summary

1. Changing the dampener pre-charge altered the frequency at which pulsations were more effectively damped
2. For most pressure ratios, 1st and 2nd orders had lower amplitude pulsations with 70% pre-charge
3. 3rd and 4th orders generally had lower amplitude pulsations with 80% pre-charge
4. An average of 12% difference in pulsation amplitudes by varying pre-charge

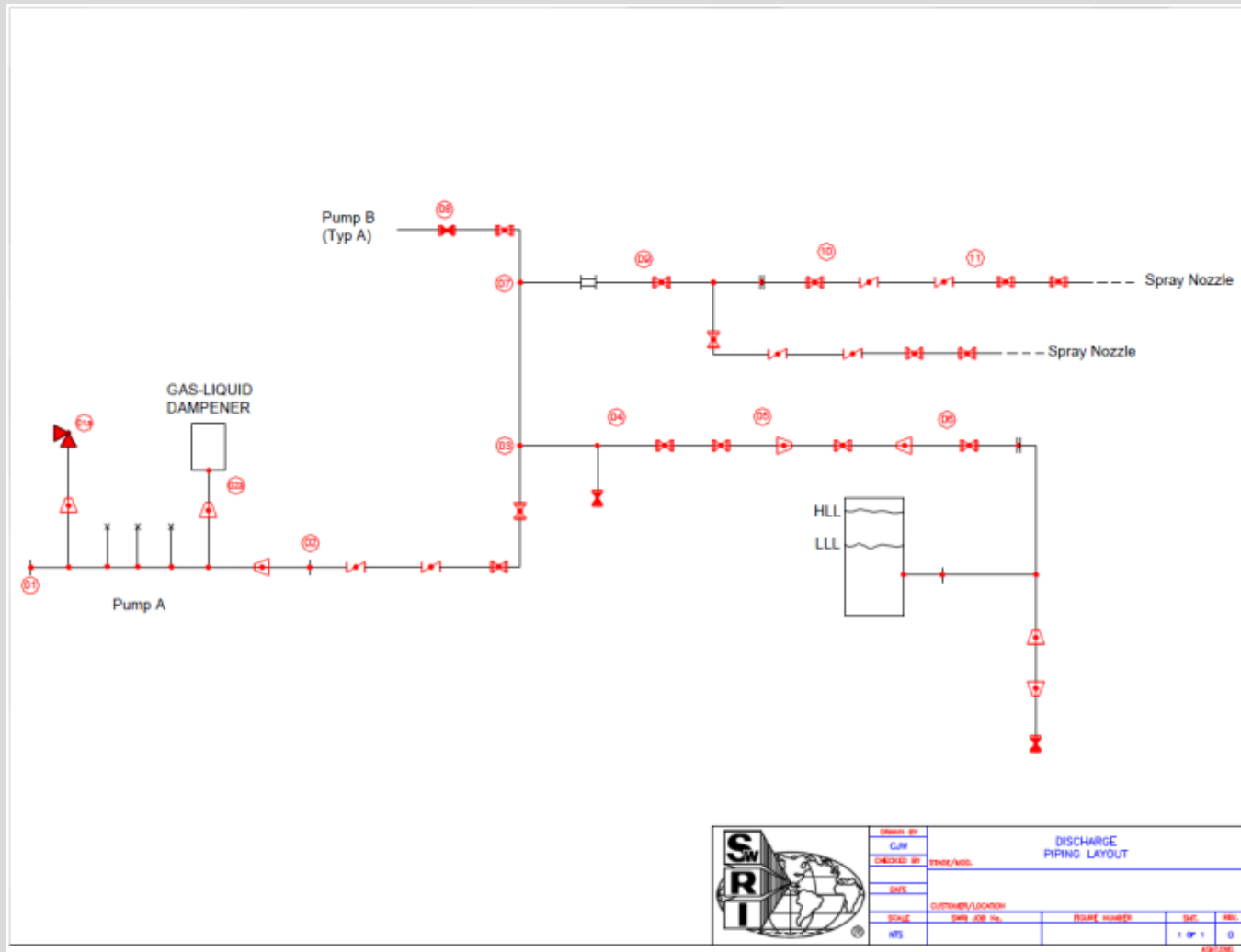
Modeling Results Comparison to Test Data



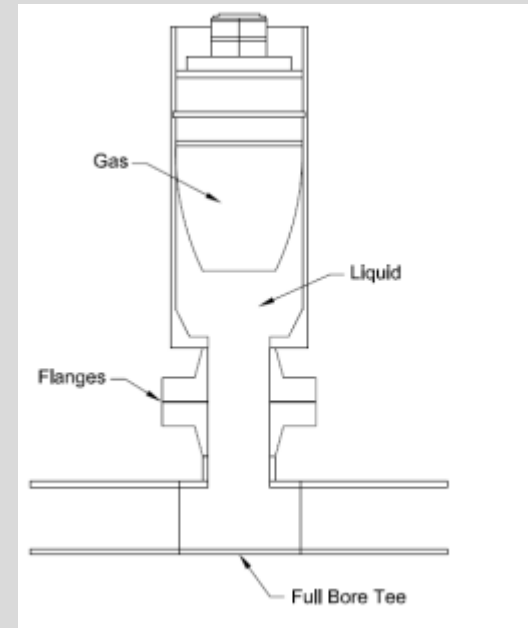
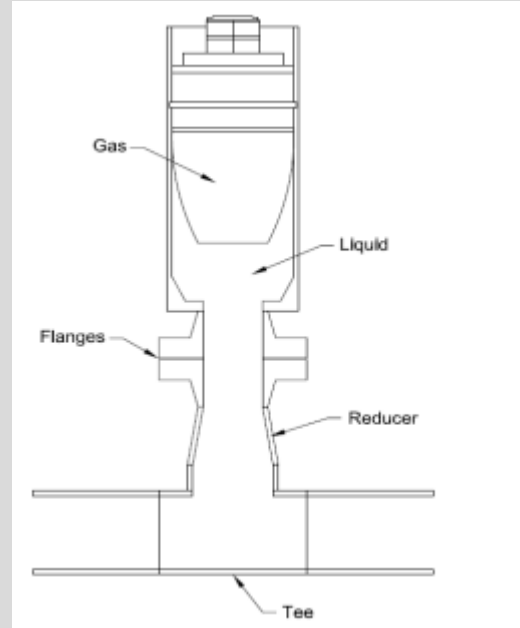
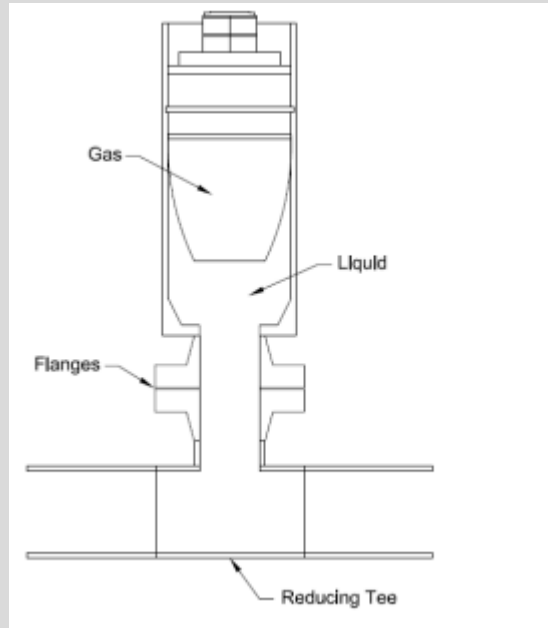
Gas-Liquid Dampener Precharge: 80% Pressure Ratio of 6.6



Extended to Client's Typical Pump Configuration



Dampener Tee Comparisons

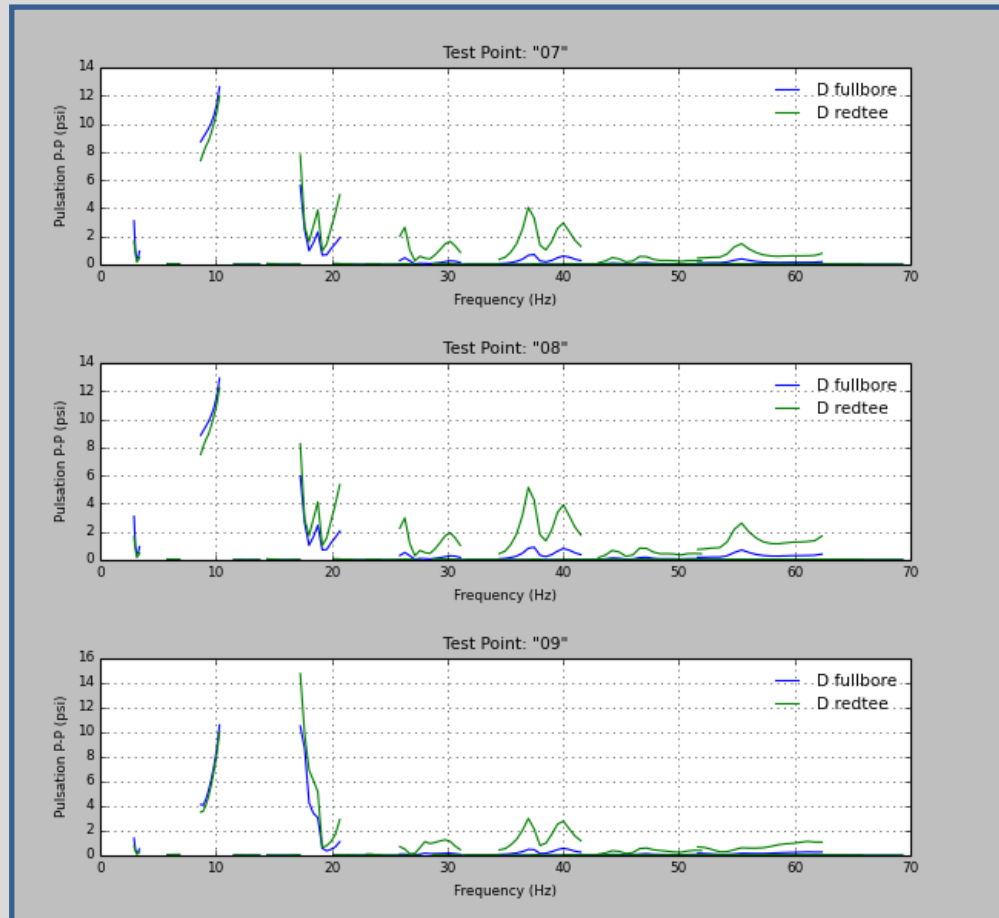


How do these three different configurations compare for attenuating pulsation amplitudes in the piping system?

Dampener Diameter Connection

Is there a significant improvement using a full-bore tee (2x2x2-inch) vs. a reducing tee (2x2x1-inch)?

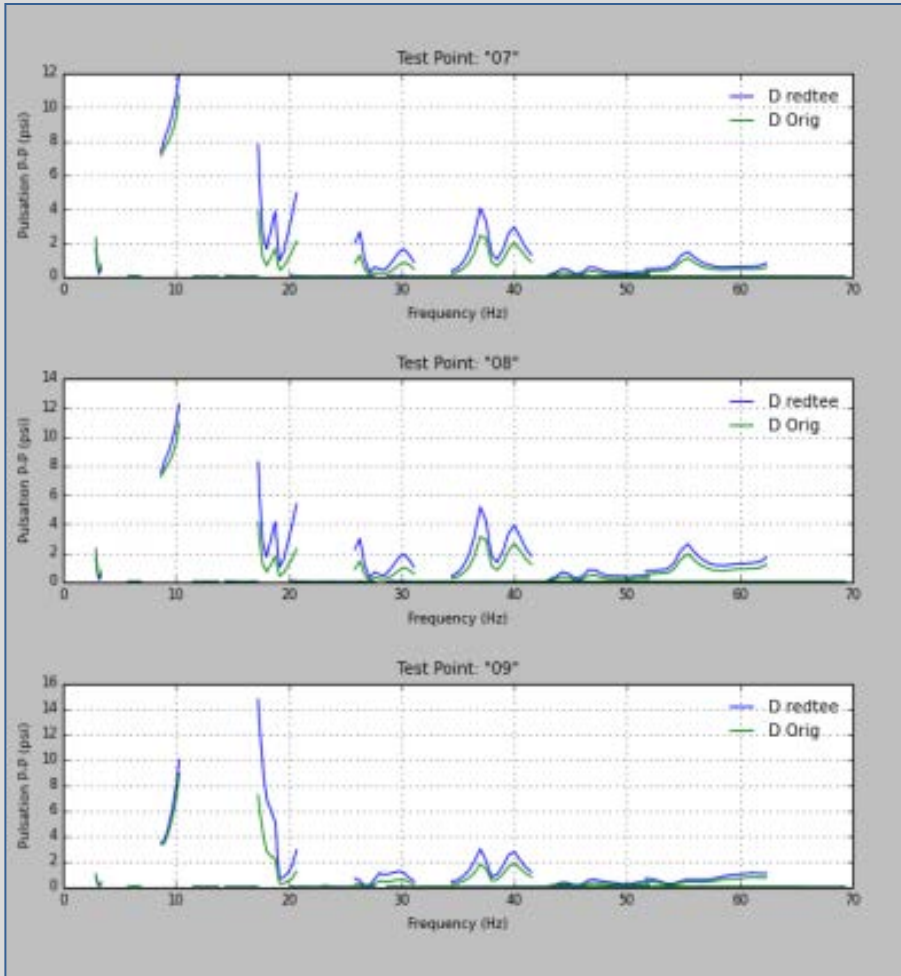
Note: Pump running speed of 190 rpm with 5% sweep



Increasing the flow area to the dampener at the tee connection provided up to 30% reduction in pulsation amplitudes at maximum amplitudes

Tee Connection

For dampeners with small inlet connections, better to use a reducing tee or full bore tee connection with reducer?



- Several cases run with varying the diameter ratio of the main line to the dampener connection
- Not always clear cut rule as the answer will depend on the diameter ratio. Adding a reducer increases length to dampener.
- For this case, with a 2:1 diameter ratio, 10-50% reduction in pulsation amplitudes with full bore tee reducer
- Needs modeling on a case-by-case basis

Summary and Lessons Learned

- What is the effect on pulsation amplitudes in positive displacement pump systems by altering various characteristics of gas-liquid dampeners?
- Dampener Pre-Charge
 - Pre-charge can be “tuned” to vary primary pulsations damped
 - Typically recommend pre-charge varied between 60-85% of line pressure
- Dampener Piping Connection
 - Use of a full-bore tee is ideal with larger dampener connection
 - If not possible, for large diameter ratios can be better to use a full-bore tee with reducer, but requires modeling for more accuracy.
 - General good practice—keep dampener connection as short and wide as possible

Questions or Comments?

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